

# Evaluating the Effectiveness of Best Management Practices to Reduce Agricultural Nonpoint Source Pollution

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**Thomas H. Johengen**

*Department of Atmospheric and Oceanic Science,  
University of Michigan, Ann Arbor, Michigan 48109*

**Alfred M. Beeton**

*National Oceanographic and Atmospheric  
Administration, Great Lakes Environmental Research  
Laboratory, Ann Arbor, Michigan 48105*

**Dennis W. Rice**

*Washtenaw County Soil Conservation District,  
Ann Arbor, Michigan 48103*

## ABSTRACT

The Saline Valley project is one of 20 national projects sponsored by the U.S. Department of Agriculture (USDA) under the Rural Clean Water Program (RCWP) to evaluate methods of controlling agricultural nonpoint source pollution. The goals of this project were (1) to evaluate whether a voluntary approach using cost-share incentives would produce adequate participation by local farmers and (2) to reduce phosphorus loads from the area by 40 percent. Water quality has been monitored since 1981 using weekly grab samples and flow measurements. Trends in empirical relationships between concentration and discharge at three sampling stations were used to examine the effectiveness of best management practices (BMP). These relationships were highly variable among the sub-basins and years, and did not appear to correlate with areal estimates of BMP implementation. Overall, low participation within the project area hindered the ability to quantify changes in water quality resulting from BMP implementation and prevented the project from meeting its phosphorus reduction goals.

## Introduction

Saline Valley is one of 20 national projects within the U.S. Department of Agriculture's Rural Clean Water Program designed to evaluate the effectiveness of best management practices in controlling nonpoint source pollution. BMPs include agronomic practices such as conservation or reduced tillage, crop rotation, vegetative cover, crop residue, and nutrient management, as well as structural devices such as grassed waterways, sediment retention basins, erosion control weirs, and animal waste holding tanks. These practices are designed to reduce sediment and nutrient transport from the farms into surrounding lakes and streams. They may also provide

on-site benefits by improving long-term soil productivity (Myers, 1986) and reducing operational costs in fuel and fertilizers (Young and Magleby, 1987).

Saline Valley was targeted as a study site because it was identified in a regional 208 water quality plan as the most concentrated area of rural nonpoint source pollution in southeast Michigan (Anon. 1983). Located in Washtenaw and Monroe Counties, the study site covers approximately 77,000 acres (Fig. 1). The area is divided into seven distinct drainage basins, each containing a monitoring station, with an eighth station at the confluence of the Saline River with the River Raisin. Results presented here address stations 4, 7, and 9, drainage basins that have completely contained streams and are not affected by any known

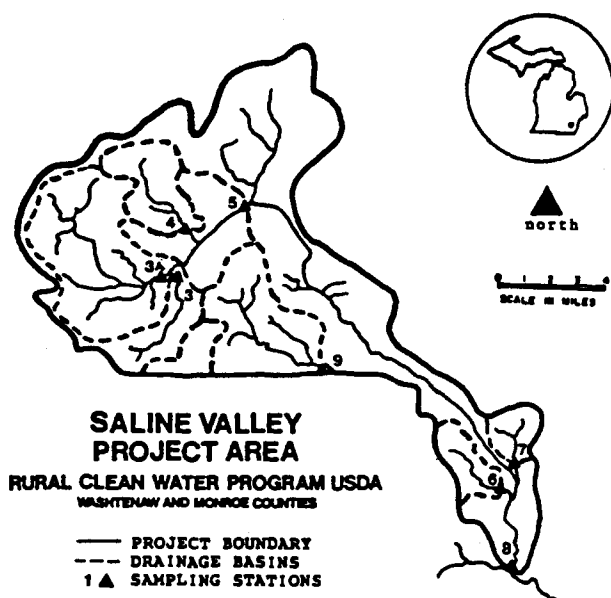


Figure 1.—The Saline Valley RCWP study area. Covers 77,000 acres and is located in Washtenaw and Monroe Counties, MI.

point sources. Consequently, they offer the best opportunity to evaluate water quality changes resulting from BMP implementation within their watersheds.

Participation in the project was voluntary, with cost share provided by the Agricultural Stabilization and Conservation Service and technical assistance offered through the Soil Conservation Service as incentives for farmers to implement recommended BMPs. From previous experience in implementing federal programs among farmers, USDA concluded that regulation did not work well in the agricultural sector and the voluntary approach proved more effective (Meyers, 1986). It was also shown that participation depends strongly on available financial support to offset costs involved in implementing recommended changes (Kerns and Kramer, 1985). Therefore, the success of any future nonpoint source pollution program will be a function of both the farmers' attitudes toward proposed management practices and the availability of cost-share funds.

The overall goal of the Saline Valley RCWP was to reduce the annual phosphorus loads from the project area by 40 percent. Strategies designed to meet this goal called for reducing phosphorus losses from fertilizer application by half and from animal wastes by 30 percent; and both sediment and phosphorus losses from cropland soil erosion by 30 percent. It is important for farmers to realize that, while such phosphorus losses from their farms are often not important agronomically (i.e., a small percentage of the inputs), they do represent significant loading to lakes

and streams that can accelerate eutrophication (Sharpley et al. 1988).

This paper describes observed changes in water quality over time and examines their correlation with the best management practices implemented in the watershed. Secondly, it evaluates whether the voluntary approach met the project's participation and water quality goals.

## Study Approach

### Analytical

Grab samples and discharge measurements were collected between 30 and 40 times per year usually at weekly intervals for stations 4 and 7 beginning July 1981. Sampling at station 9 did not begin until September 1982. The monitoring program will continue until the end of 1989. Discharge was measured from water level readings taken from a fixed reference point on a bridge, using U.S. Geological Survey-established rating curves. Water samples were analyzed for ammonium, nitrate-nitrite, soluble-reactive phosphorus, chloride, and silica on an auto analyzer II within 24 hours according to the methods of Davis and Simmons (1979). As nitrite consistently represented less than 1 percent of nitrate, nitrate-nitrite is subsequently referred to as nitrate. Total phosphorus was determined on unfiltered water using a potassium persulfate digestion method. Available phosphorus was determined on material retained on a 0.45  $\mu$ m nucleopore filter by extraction in 0.1 M sodium hydroxide. Suspended solids were determined gravimetrically for material retained on a Whatman GF/C filter. Raw data along with estimates of seasonal and annual loads are available from the authors in a series of Interim reports.

### BMP Implementation

One of the key challenges facing Rural Clean Water Program projects is to adequately quantify the extent of BMP implementation. This process is critical for tracking progress and for interpreting water quality data (Maas et al. 1988). For this study, implementation was quantified according to the total acreage where the BMP was applied, or in the case of structural practices over the acreage it influenced. Acreage contracted under crop rotation plans were not included in these calculations because the large number of acres would mask all other BMPs and it is

difficult to delineate crop rotation effects into individual years. Estimates of tons of soil saved using the universal soil loss equation indicated permanent vegetative cover applied to critical areas, pasture plantings, and conservation tillage all had similar areal effects. It was difficult to assess the equivalency of other BMPs applied. However, using areal estimates should still produce meaningful comparisons between water quality and BMP implementation over time and between sub-basins.

## Water Quality Trends

In assessing the effects of land treatment on water quality between years, one of the most important factors to account for is differences in yearly precipitation and/or runoff. One simple approach is to use regression models of concentration versus discharge established for each year (Spooner et al. 1985). This approach has been useful for describing patterns of sediment and nutrient losses from a watershed (e.g., Johnson et al. 1976) and attempts to correct for meteorologic variations between years. BMPs are designed to reduce both sediment and nutrient sources and transport from the field. Assuming a similar amount of runoff reaches the stream, when BMPs are applied the observed concentrations of these pollutants should be reduced. The effectiveness of BMPs can, therefore, be evaluated on the basis of changes in yearly empirical regressions. Since BMP implementation occurred throughout the study period, no true before/after comparisons could be made. Instead, comparisons were made between water quality and levels of BMP implementation for individual years.

This approach was chosen over comparisons between estimated annual loads for several reasons. First, the lack of continuous discharge records at any station greatly reduced the accuracy of a loading estimate, and, more importantly, it hindered normalizing loads for differences in the amount of yearly discharge. Differences in annual loads arising from meteorological variation must be separated from those resulting from land treatment.

For this data set, log-transformed concentrations were used to meet skewness and kurtosis requirements. Data were also stratified by flow regime and only sampling periods with discharges above the yearly median were used in the regressions. This approach was used to strengthen correlations and remove the high variability that occurred at low flows. Previous analyses using all data indicated no differences in concentration patterns between years at low flow periods; therefore, little sensitivity was lost. Correlations between concentration and BMP levels were examined at flow regimes of 0.1 and 0.5 m<sup>3</sup>sec<sup>-1</sup>. These represent typical mean and high flow levels.

## Results and Discussion

### BMP Implementation

Annual summaries of the numbers of BMPs applied within the sub-basins revealed overall participation was low. Areal estimates of BMP implementation in sub-basin 4 ranged from 7 to 14 percent of the watershed throughout the study period (Table 1). BMP implementation within sub-basin 7 was also low, ranging from 13 to 21 percent of the watershed (Table 2). The combination of low participation levels and small changes in those levels between years minimized the chances of detecting any effects on water quality. Unknown changes within the non-participating areas could easily mask the effects of those areas under implementation. Participation within sub-basin 9 was much higher and showed greater variability between years (Table 3). The highest amount of implementation occurred in 1985 when approximately 56 percent of the area was under BMPs. Participation levels dropped off after that time as contract obligations ended. By 1987 coverage was down to only 22 percent of the watershed.

The levels of participation within the Saline Valley project sharply contrast with those from other Rural Clean Water Program projects. According to a summary by Maas et al. (1988), all other projects have achieved or exceeded their BMP implementation goals with between 60 and 100 percent of their study area under contract. The low response by area farmers could have resulted from several factors, including inadequate contact from local Cooperative Extension Service personnel or simply from negative attitudes toward the BMPs farmers were being asked to adopt.

### Water Quality Trends

Water quality patterns for suspended solids (SS), total phosphorus (TP), soluble reactive phosphorus (SRP), and nitrate (NO<sub>3</sub>) were examined using linear regressions between log concentration and discharge. Correlation coefficients for the resulting regressions varied greatly between parameters and years (Table 4).

Differences between regression patterns of the various pollutants may lend insight into their behavior and transport within the sub-basins. Regressions at station 4 were significant for suspended solids, total phosphorus, and soluble reactive phosphorus each year and for nitrate three of six years. Finding both particulate and dissolved pollutants correlated to discharge, suggests similar transport mechanisms via

Table 1.—Annual summary of best management practices applied within sub-basin 4 (4900 ac). Areal amounts for structural BMP's are estimated for acreage affected based on site location. BMP's with permanent effects (bold faced) are summed for each year and carried over to the following year.

YEAR	TYPE OF BMP	AMOUNT (UNIT)	AMOUNT (ACRE)	TOTALS (ACRES)	AREAL PERCENT
1982	carry-over		0		
	<sup>1</sup> AWMS-spreading plan	90 ac	90		
	Conservation tillage	200 ac	200		
	Erosion control structure	1 no	25	630	12.9
	<sup>2</sup> CPS-cover crop	45 ac	45		
	CPS-residue management	170 ac	170		
	AWMS-subsurface drains	9000 ft	10		
1983	AWMS-spreading plan	90 ac	90		
	carry-over		35		
	AWMS-spreading plan	90 ac	90		
	Conservation tillage	200 ac	200		
	CPS-residue management	90 ac	90	665	13.6
	Waterway system-grassed	1 ac	80		
	Waterway system-drains	3020 ft	80		
1984	AWMS-spreading plan	90 ac	90		
	carry-over		195		
	Conservation tillage	105 ac	105	330	6.7
1985	CPS-residue management	30 ac	30		
	carry-over		195		
	AWMS-spreading plan	90 ac	90		
	Conservation tillage	60 ac	60	465	9.5
	CPS-residue management	30 ac	30		
1986	AWMS-spreading plan	90 ac	90		
	carry-over		195		
	AWMS-spreading plan	85 ac	85		
	Conservation tillage	90 ac	90	500	10.2
	CPS-residue management	30 ac	30		
1987	<sup>3</sup> PVC-pasture planting	15 ac	15		
	AWMS-spreading plan	85 ac	85		
	carry-over		210		
	AWMS-spreading plan	85 ac	85	430	8.8
	Conservation tillage	50 ac	50		
	AWMS-spreading plan	85 ac	85		

<sup>1</sup>AWMS: Animal waste management system

<sup>2</sup>CPS: Crop protection system

<sup>3</sup>PVC: Permanent vegetative cover

Lake and Reservoir Management, like other journals of aquatic science, publishes data in the metric system of units. Acreage data in this paper is being printed as a courtesy to the authors since conversion would require extensive revision. This exception should not be construed as a change in editorial policy. —Editor

overland runoff. The overall regression patterns for suspended solids, total phosphorus, and soluble reactive phosphorus at station 4 were quite similar (Fig. 2). The yearly order of the concentrations at discharges above  $0.3 \text{ m}^3\text{sec}^{-1}$  were the same for all three parameters, with the exception that the two highest for suspended solids were switched. The most noticeable trend at this station was that 1982 regressions had much higher intercepts and shallower slopes than for other years. This pattern may have resulted from a more intense sampling scheme during the first year of the project when extra sampling was performed after storm events.

The pattern at station 7 was quite different in that very few regressions were significant and those for nitrate had negative slopes. These results suggest pollutant inputs at this station were not primarily from overland runoff and nitrate levels were actually diluted

by higher amounts of runoff. Substantial underground inputs of nitrate are common in many agricultural areas because it is highly soluble and easily transported through soils. Many of the fields adjacent to the stream are tile drained and high concentrations of nitrate probably reached the sampling station from subsurface flow collected in the tiles. In general, BMPs designed mainly to reduce overland transport may be ineffective in reducing levels of nitrate, especially where a rapid transport from groundwater to a surface stream exists.

Results from station 9 resembled those of station 4 in that all suspended solids and total phosphorus regressions were significant; however, those for soluble reactive phosphorus and nitrate were mostly insignificant. These results may be typical of small streams within agricultural watersheds where particulate species transport is closely related to periods of

Table 2.—Annual summary of best management practices applied within sub-basin 7 (1920 ac). Areal amounts for structural BMP's are estimated for acreage affected based on site location. BMP's with permanent effects (bold faced) are summed for each year and carried over to the following year.

YEAR	TYPE OF BMP	AMOUNT (UNIT)	AMOUNT (ACRE)	TOTALS (ACRES)	AREAL PERCENT
1982	carry-over		0		
	<sup>1</sup> AWMS-spreading plan	115 ac	115		
	Conservation tillage	130 ac	130	360	18.8
	AWMS-storage facility	1 no	—		
	AWMS-spreading plan	115 ac	115		
1983	carry-over		0		
	AWMS-spreading plan	115 ac	115		
	Conservation tillage	50 ac	50	365	19.0
	<sup>2</sup> CPS-residue management	85 ac	85		
	AWMS-spreading plan	115 ac	115		
1984	carry-over		0		
	AWMS-spreading plan	115 ac	115		
	Conservation tillage	85 ac	85	400	20.8
	CPS-residue management	85 ac	85		
	AWMS-spreading plan	115 ac	115		
1985	carry-over		0		
	AWMS-spreading plan	115 ac	115		
	Conservation tillage	50 ac	50	365	19.0
	CPS-residue management	85 ac	85		
	AWMS-spreading plan	115 ac	115		
1986	carry-over		0		
	AWMS-spreading plan	85 ac	85		
	Conservation tillage	85 ac	85	255	13.3
	AWMS-spreading plan	85 ac	85		
1987	carry-over		0		
	AWMS-spreading plan	85 ac	85		
	Conservation tillage	85 ac	85	255	13.3
	AWMS-spreading plan	85 ac	85		

<sup>1</sup>AWMS: Animal waste management system

<sup>2</sup>CPS: Crop protection system

high discharge, but dissolved species transport is obscured by the dynamic nature of cycling and transport.

The pattern of the regressions at station 9 differed from station 4. In addition, the yearly order of concentrations at high discharges was different between suspended solids and total phosphorus (Fig. 3). The difference between sub-basins is not surprising given the potential for spatial variability in topography, soils, farming intensity, and climatic patterns. It is somewhat more surprising that suspended solids and total phosphorus did not follow similar patterns. The discrepancy suggests that the major source of total phosphorus may not be bound to soil particles. The runoff patterns for total phosphorus may reflect the much higher intensity of animal farming occurring within this sub-basin.

The relationship between water quality and BMPs was examined by plotting predicted concentration at discharges of 0.1 and 0.5 m<sup>3</sup> sec<sup>-1</sup> — taken from yearly regressions — against yearly estimates of the number of BMPs implemented within the watershed (Fig. 4, 5). At station 4 predicted concentrations for a dis-

charge of 0.5 m<sup>3</sup> sec<sup>-1</sup> varied by a factor of 2 among individual parameters but were not correlated to the levels of BMPs. Predicted concentrations at a discharge of 0.1 m<sup>3</sup> sec<sup>-1</sup> appeared to actually increase with higher levels of BMP implementation, however it is doubtful that such a negative effect is real. Given the number of BMPs applied varied by only 7 percent between years, it is unrealistic to believe a true treatment effect was reflected between years, especially since only a small portion of the watershed was involved.

At station 9 concentrations at high flows also appeared to increase with higher levels of BMPs but no trend was seen for those at the lower flows (Fig. 5). The differences in percent of BMP coverage between years should have been great enough to exhibit a treatment effect (between 12 and 56 percent). However, it is again difficult to believe that such a negative effect is real. Such a relationship forces close examination of the analyses assumptions and those variables over which the study has no control. The most obvious problem was difficulty in assessing the effects of the non-participating areas on water quality. Even when dealing with fairly small watersheds the

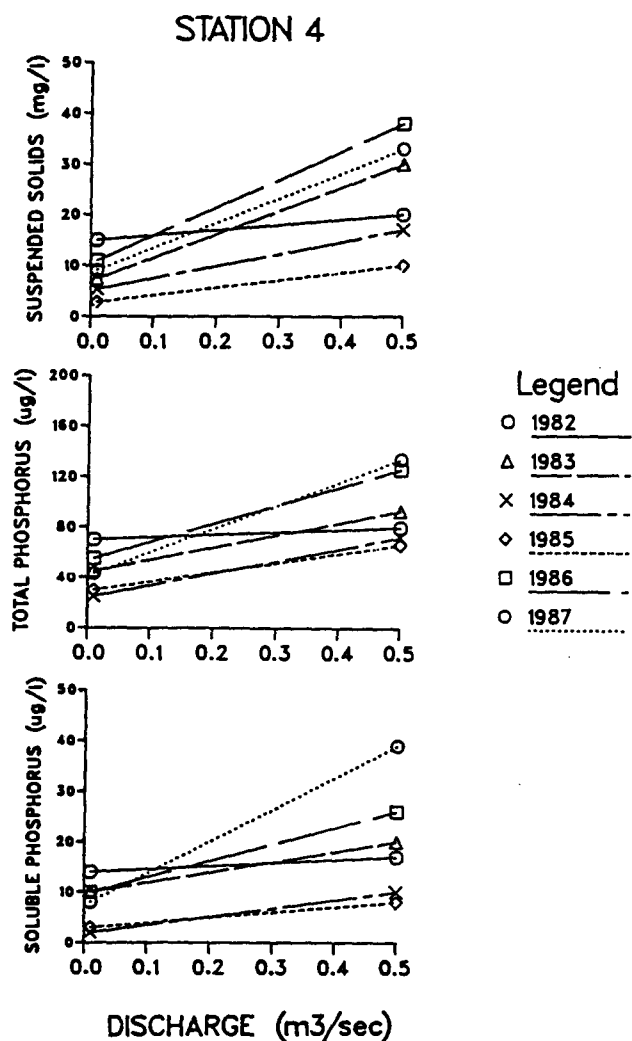


Figure 2.—Annual regression for log concentration versus discharge for suspended solids, total phosphorus, and soluble reactive phosphorus at station 4. Data points for regressions include only those sampling periods with discharge greater than the yearly median.

variations in sources and transport of sediment and nutrient over time are so large that it may be impossible to establish meaningful trends for a single sampling site. Another problem is the difficulty in assessing accuracy or meaningfulness of areal estimates of BMP implementation. Individual BMPs may vary in effectiveness. They may also have competing effects. BMPs designed to reduce soil erosion greatly reduce the volume of runoff (e.g., Mostaghimi et al. 1987), which could actually increase concentrations within the stream. Concentration-discharge relationships may be useful for accessing the effects of land treatment within the watershed, however an intensive monitoring program is required to overcome temporal and spacial variations. Personnel and cost constraints within the Saline Valley project prevented this effort from being sufficient. Ideally, to establish a true

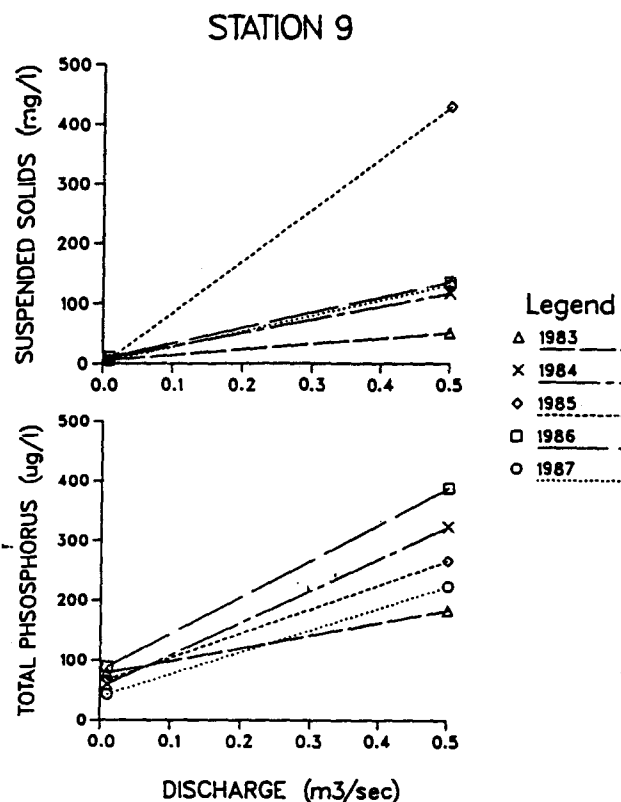


Figure 3.—Annual regression for log concentration versus discharge for suspended solids and total phosphorus at station 9. Data points for regression include only those sampling periods with discharge greater than the yearly median.

relationship between BMPs and water quality the study must be applied where all land treatment is completely known or controlled and sampling intensity is adequate.

## Conclusions

USDA initiated the Rural Clean Water Program in 1980 to help define strategies for controlling agricultural nonpoint source pollution. The program used a voluntary approach, with technical and cost-share assistance to encourage farmers to implement recommended best management practices. These practices are designated to protect water resources by reducing the loads of sediments and nutrients entering lakes and streams. BMPs may also provide additional on-site benefits by maintaining increased productivity and reducing costs for fertilizers and fuel.

In the Saline Valley RCWP low participation levels hindered the ability to demonstrate the effectiveness of BMPs in improving local water quality. As indicated by yearly regressions between concentration and discharge, this voluntary approach did not produce the

**Table 3.—Annual summary of best management practices applied within sub-basin 9 (9730 ac). Areal amounts for structural BMP's are estimated for acreage affected based on site location. BMP's with permanent effects (bold faced) are summed for each year and carried over to the following year.**

YEAR	TYPE OF BMP	AMOUNT (UNIT)	AMOUNT (ACRE)	TOTALS (ACRES)	AREAL PERCENT
1983	carry-over		20		
	<sup>1</sup> AWMS-spreading plan	370 ac	370		
	Conservation tillage	370 ac	370		
	CPS-residue management	100 ac	100	1025	10.5
	Erosion control structure	2 no	35		
	Waterway system-grassed	1 ac	30		
1984	Waterway system-drains	25000 ft	100		
	carry-over		185		
	AWMS-spreading plan	1780 ac	1780		
	Conservation tillage	395 ac	395		
	AWMS-storage facility	1 no	—	2595	26.7
	<sup>2</sup> CPS-cover crop	35 ac	35		
1985	AWMS-subsurface drains	15000 ft	100		
	CPS-residue management	100 ac	100		
	carry-over		285		
	AWMS-spreading plan	1770 ac	1770		
	Erosion control structure	2 no	10		
	Conservation tillage	3320 ac	3320	5500	56.5
1986	<sup>3</sup> PVC-pasture planting	30	30		
	CPS-residue management	65 ac	65		
	CPS-cover crop	25 ac	25		
	carry-over		325		
	AWMS-spreading plan	785 ac	785		
	Waterway system-grass	1.4 ac	20		
1987	Sediment control basin	1 no	15	3025	31.1
	Conservation tillage	975 ac	975		
	CPS-residue management	65 ac	65		
	PVC-pasture planting	55 ac	55		
	carry-over		415		
	AWMS-spreading plan	1140 ac	1140		
1987	PVC-pasture planting	20 ac	20		
	Waterway system-grass	3.7 ac	30		
	Waterway system-drains	7055 ft	15	2100	21.6
	Conservation tillage	295 ac	295		
	Erosion control structure	6 no	100		
	CPS-cover crop	10 ac	10		
	CPS-residue management	75 ac	75		

<sup>1</sup>AWMS: Animal waste management system

<sup>2</sup>CPS: Crop protection system

<sup>3</sup>PVC: Permanent vegetative cover

participation levels needed to meet the project goal of a 40 percent reduction in phosphorus loads derived from nonpoint sources. If a voluntary approach is to be used on a national level to deal with agricultural nonpoint source pollution then obtaining adequate participation must be paramount. Targeting critical areas, individual contact, educating area farmers about the benefits of BMPs and the availability of cost-share dollars have all been recognized as critical steps in the Rural Clean Water Program experiment.

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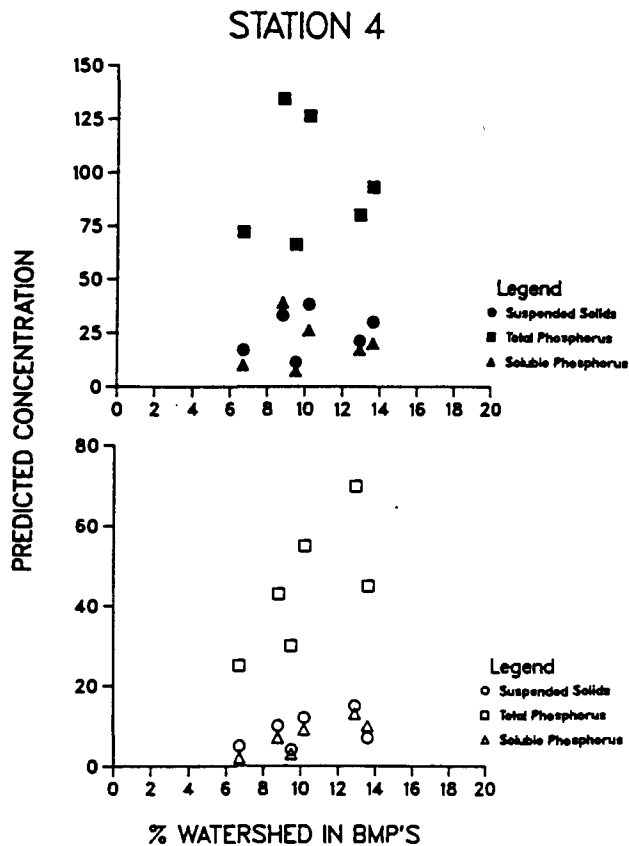


Figure 4.—Predicted concentrations for suspended solids (mg/L), total phosphorus ( $\mu\text{g/L}$ ), and soluble reactive phosphorus ( $\mu\text{g/L}$ ) at discharges of 0.5 (closed symbols) and 0.1 (open symbols)  $\text{m}^3\text{sec}^{-1}$  plotted against areal estimates of the percent of sub-basin 4 under BMP implementation.

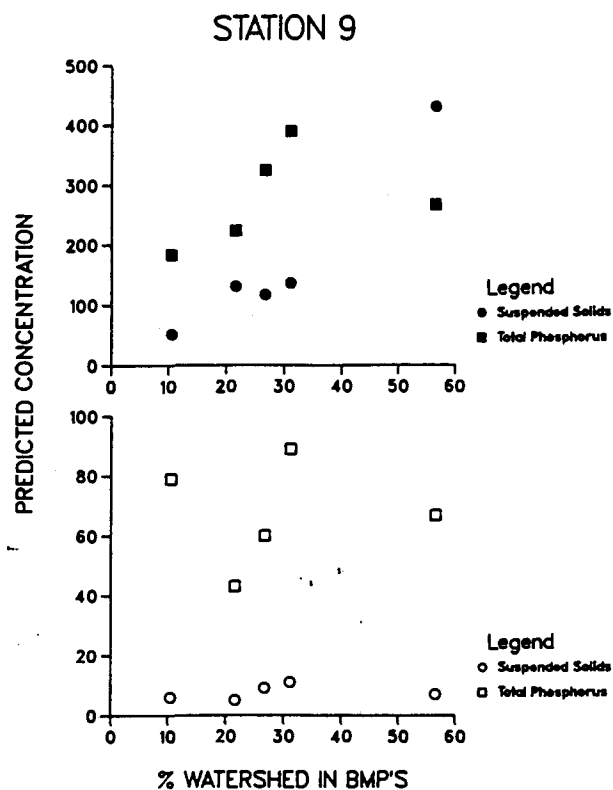


Figure 5.—Predicted concentrations for suspended solids (mg/L) and total phosphorus ( $\mu\text{g/L}$ ) at discharges of 0.5 (closed symbols) and 0.1 (open symbols)  $\text{m}^3\text{sec}^{-1}$  plotted against areal estimates of the percent of sub-basin 9 under BMP implementation.

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Table 4.—Correlation coefficients for empirical models of log concentration versus discharge. (Regressions with alpha > .05 reported as NS).

STATION	YEAR	<sup>1</sup> SS	<sup>2</sup> TP	<sup>3</sup> SRP	<sup>4</sup> NO <sub>3</sub>
4	1982	.54	.46	.54	NS
	1983	.82	.72	.55	NS
	1984	.69	.75	.81	.63
	1985	.67	.81	.67	NS
	1986	.86	.75	.74	.48
	1987	.62	.80	.91	.70
7	1982	NS	NS	NS	-.71
	1983	NS	NS	NS	-.51
	1984	NS	NS	NS	-.48
	1985	.66	NS	NS	NS
	1986	.61	.71	NS	-.44
	1987	NS	NS	NS	NS
9	1983	.60	.72	NS	.50
	1984	.69	.85	.65	NS
	1985	.67	.67	NS	NS
	1986	.82	.75	NS	NS
	1987	.71	.71	.65	NS

<sup>1</sup>SS: Suspended solids

<sup>2</sup>TP: Total phosphorus

<sup>3</sup>SRP: Soluble reactive phosphorus

<sup>4</sup>NO<sub>3</sub>: Nitrate